Respiratory Medicine CME 2 (2009) 1–6

Contents lists available at ScienceDirect

Respiratory Medicine CME

journal homepage: www.elsevier.com/locate/xxx

CME Article

A review diaphragmatic injury

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Keywords:
Diaphragmatic rupture
Blunt trauma
Penetrating wound

A B S T R A C T

Diaphragmatic injury presents a diagnostic challenge to any physician. We examine the current literature on diaphragmatic injury, its incidence, clinical presentation, diagnostic tools, treatment options and complications. We also examine the development and anatomy of the diaphragm and review the theories related to how injuries occur.

Educational aims

- To review the current literature on diaphragmatic injuries
- To examine proposed mechanisms of injury
- To review appropriate investigations if diaphragmatic injury is suspected
- To describe surgical management and the complications that can arise from delays in treatment.

1. Introduction

Diaphragmatic injuries (DIs) can occur following both blunt and penetrating trauma. Their presentation can be immediate or delayed and they are often in combination with other more severe injuries. The immediate difficulty is assessing and diagnosing these patients in the light of variable clinical and radiological signs. They often result in herniation of abdominal viscera into the thoracic cavity. The diagnostic conundrum faced by emergency physicians and trauma surgeons alike has been improved in recent times with the introduction of more sophisticated radiological investigations. However, delay in presentation can lead to complications and increased mortality. Surgical treatment options have varied very little over the years and serve to return viscera to its correct anatomical position.

2. Incidence

The incidence of diaphragmatic injuries has been reported as ranging from 1 to 7% of all patients with significant blunt trauma, and 10 to 15% with penetrating wounds,[1] although local incidence as low as 0.2% has been reported.[2] In a recent review of 53,031 patients admitted to trauma centres, a total of 592 were found to have DIs, accounting for 3% of all patients.[3]

In another review of 952,242 patients in 565 trauma centres in the USA over a period of 4 years, 6038 patients had diaphragmatic injuries (0.63%).[4] True incidence is difficult to ascertain due to missed and delayed diagnosis, and also through inconsistencies in the classification of different groups of trauma patients. Furthermore many patients may not attend hospital due to pre-hospital deaths. One review looked at 8210 subjects that had either died at accident sites (3533 subjects) or been treated for thoraco-abdominal trauma-TAT (4857 subjects). Following investigation, had all the subjects survived, the overall incidence of diaphragmatic injury would be 2.6% (2.1% of those treated for TAT, 3.3% of those who died at the accident site).[5] Because of reporting inconsistencies, the true incidence is difficult to measure, and varies considerably. It is presumed that actual incidence of diaphragmatic injuries is increasing, primarily due to the rise in the numbers of road traffic accidents (RTAs) per year.[6]

The ratio of blunt vs. penetrating trauma will vary geographically, with penetrating injuries occurring predominantly in inner city areas. In one review, reports of blunt trauma accounts for 35% of all diaphragmatic injuries, and penetrating 65%.[4] In a review of 1589 patients 75% of patients had left sided injuries, 23% had right sided injuries, and 2% had bilateral injuries.[3] This preponderance for left sided injuries is thought to be related to the protective effect of the bare area of the liver in contact with the diaphragm on the right.[3]

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1755-0017/$ – see front matter © 2009 Published by Elsevier Ltd.
doi:10.1016/j.rmedc.2009.01.002

3. Historical perspective

Diaphragmatic injuries were first described in a letter written by Sennertus to Hildani in 1541, who documented an autopsy finding of a herniated stomach through a diaphragmatic injury caused by a self-inflicted stab wound 7 months earlier.[7] In 1791 Paré described two patients who died from strangulated intra-abdominal organs, explaining that "the stomach and intestine are sometimes drawn into the thoracic cavity".[8,9] The first was a French artillery captain who sustained an abdominal gunshot wound 8 months earlier, and subsequently developed colonic strangulation through the perforated diaphragm; the second patient suffered a blunt rupture of the diaphragm with gastric incarceration.[10]

The first ante-mortem diagnosis is accredited to Bowditch in 1853, and Riolfi performed the first successful repair in 1886.[8] Walker diagnosed and repaired the first acute blunt diaphragmatic rupture, whilst treating a patient crushed by a falling tree (reported 1900).[11] The first case series of 378 cases was published in 1925 by Headbloom, marking the start of the modern surgical era in treating diaphragmatic injury.[3]

4. Anatomy of the diaphragm

The diaphragm is a bi-domed structure, which separates the contents of the thorax from the abdominal cavity. Embryologically it is derived from three sources, the septum transversum, the body wall and pleuroperitoneal membranes, and the dorsal mesentery of the oesophagus. The septum transversum separates the pericardial development from the developing gut. It descends from the neck eventually forming the central tendon. Malformation here can lead to an antero-medial parasternal defect in the Space of Larry, which can lead to a diaphragmatic hernia of Morgagni. The transverse layer of the body wall and the pleuroperitoneal membranes grow inwards to fuse with the septum transversum to form the diaphragm. Malformation of the pleuroperitoneal canals can lead to a posterior congenital diaphragmatic hernia of Bochdalek, occurring on either side of the spine more commonly on the left due to the protective effect of the liver.[12] The dorsal mesentery of the oesophagus completes the posterior part of the diaphragm. Anatomically, the diaphragm is composed of a thin leaflet of central aponeurosis in continuity with peripheral striated muscle, and is divided into two parts: the lumbar diaphragm and costal diaphragm. It originates anteriorly from the xiphoid, sternum, and the ribs and costal cartilages of ribs 7–12, as well as posteriorly from the lumbar vertebrae by means of the left and right crura. The right crus is attached to lumbar vertebrae L1, L2 and L3 and the left crus attaches to L1 and L2. There are the lateral and medial arcuate ligaments also completing the origin. The diaphragm inserts into the central tendon which is fused with the pericardium. There are three openings permitting the passage of three large structures. The inferior vena cava and the right phrenic nerves pass through an opening at the level of T8, the oesophagus and vagus nerves pass through an opening at the level of T10 and the abdominal aorta, thoracic duct and azygous vein pass through an opening at T12. The lumbocostal trigone, a thin area of degenerative muscle on the left diaphragm above the lateral arcuate ligament, represents an embryological transitional region between the costal and lumbar diaphragm. In certain cases, this region may be deficient in actual muscle tissue, represented only by epimysium.[13] Nerve supply is via the phrenic nerves (C3, C4 and C5) which supplies sensory and motor innervation. Its actions during respiration are responsible for 70% of the work during inspiration. It also has a role in raising intra-abdominal pressure during straining. The diaphragm is covered by parietal pleura and peritoneum, except for the bare area of the liver.[13–15]

5. Types of injury

The diaphragm can be injured in several ways, which can be broadly divided into blunt and penetrating trauma. A third group, iatrogenic injury, can also be considered. These different modes explain the differing presentations and treatments required. The commonest causes for blunt injury are RTAs and the commonest causes of penetrating injuries are knife attacks and gunshot wounds. Incidences of the two mechanisms vary geographically.

6. Pathophysiology of injury

The two mechanisms of injuries produce a variety of different diaphragmatic injuries. For example in blunt trauma, it is the abrupt change in intra-abdominal pressure that is thought to cause the majority of injuries, although shearing and/or avulsion can occur, especially following lateral trauma.[16] Normal intra-abdominal pressure varies from +2 to +10 cm H_2O during inspiration. A pressure gradient of 100 cm H_2O can be achieved across the diaphragm during the Valsalva's manoeuvre,[17] and it is these pressure gradients that are thought to exist at the moment of injury, thus contributing to it. This pressure gradient contributes to both the initial injury, and can lead to the herniation of abdominal contents through a diaphragmatic injury if presentation is delayed. Fig. 1 shows the herniation of the stomach within the left pleural cavity.

Numerous studies have shown a greater incidence of left sided diaphragmatic injuries following blunt trauma. Furthermore, studies on bursting pressures in cadavers have shown consistent weaknesses on the left side.[17] This is due to the protective effect of the liver on the right, and the location of the lumbocostal trigone on the left. It has also been suggested that the location of the oesophageal hiatus contributes to the left sided weakness.[17] Tears are generally more extensive than those caused by penetrating trauma, measuring 5–15 cm, and are typically radial[6] (Fig. 2). Penetrating injuries occur in a more random distribution, and produce smaller injuries (typically <1 cm in diameter). Associated abdominal or thoracic injuries are usually more easily identified with a simple penetrating injury, although this is not always the case.

Spontaneous diaphragmatic injury has been reported following bouts of coughing, where it has been postulated that the lack of co-ordinated movement of the respiratory muscles can result in

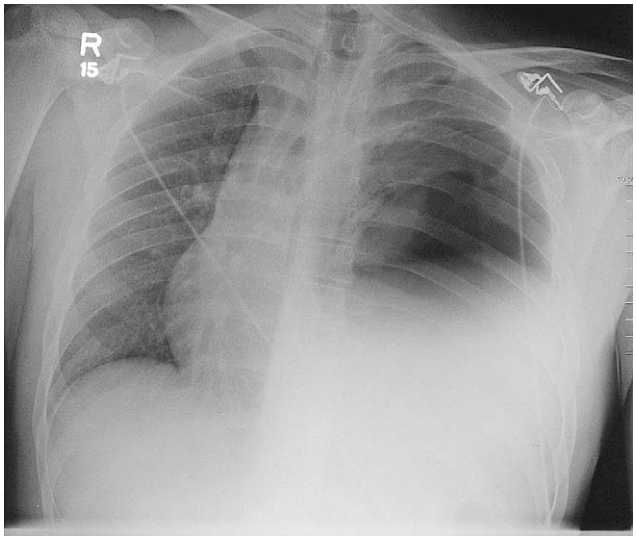

Fig. 1. Chest radiograph showing the herniation of the stomach within the left pleural cavity. Please do not confuse with pneumothorax. The air space shadow in this CXR has rounded margins.

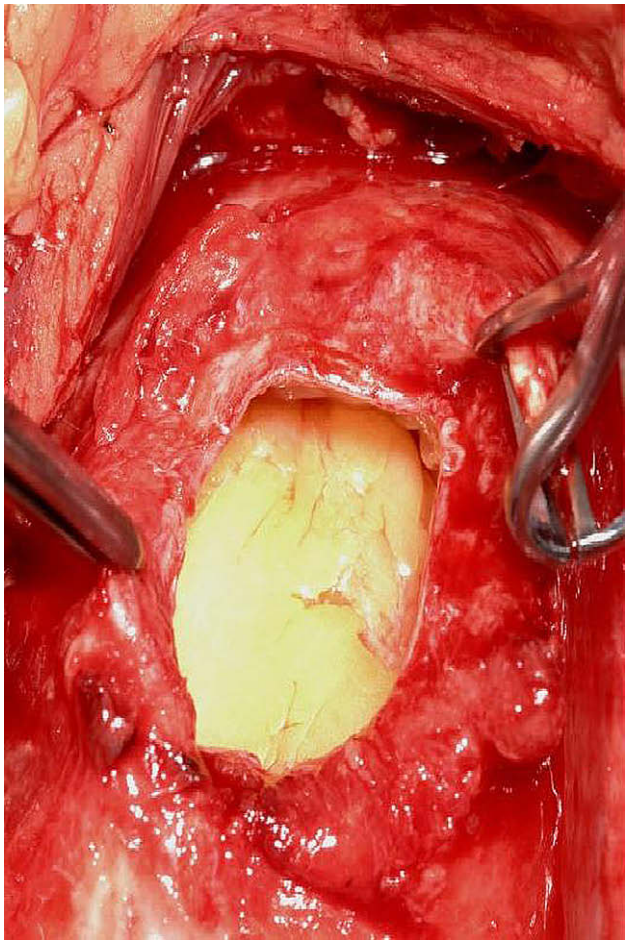

Fig. 2. Intra-operative photograph of a radial tear within the left hemi-diaphragm.

diaphragmatic tears, as well as following childbirth and heavy exercise.[18,19] In a review of 13 cases of spontaneous diaphragmatic injury, all but one suffered left sided ruptures, further highlighting the natural weakness of the left hemi-diaphragm.[20]

7. Associated injuries

A diaphragmatic injury is invariably a marker of serious trauma. The diaphragm is rarely injured alone, with an associated injury rate approaching 100%.[21] It is commonly associated with intra-abdominal injuries, thoracic injuries, fractures of the ribs, pelvis and long bones, head injuries, and rarely aortic injuries. In the event of death, it is commonly caused by a concomitant injury, rather than the diaphragmatic injury alone.

8. Diagnosing diaphragmatic injuries: clinical assessment

A timely diagnosis of diaphragmatic injury can be problematic to any trauma department. These patients invariably have other distracting and possibly life threatening injuries, and present with shock 50–60% of the time.[3] Delayed diagnosis is common, and can occur as late as 15 years following initial injury.[22] However, classical symptoms and signs can lead to a speedy diagnosis. Information on the mechanism of injury should be obtained from the patient and pre-hospital care personnel. For those involved in RTAs, information should be collected on the vehicle velocity, severity of vehicle damage, evidence of protrusion into the car, steering wheel deformity, patient location within the car, need for assisted extraction and occurrence of associated deaths. Other mechanisms which can result in blunt diaphragmatic injury include a fall from height or crush injuries.

Physical findings can be either thoracic or abdominal. Thoracic signs include decreased breath sounds, fractured ribs, flail chest, and signs of haemothorax or pneumothorax. Auscultation of bowel sounds in the chest is pathognomonic of diaphragmatic rupture, occurring due to herniation of bowel contents. Abdominal signs include abdominal pain, guarding, absence of bowel sounds, and abdominal swelling, depending on the extent of injuries. Occasionally physical examination can be relatively normal.

If diagnosis is delayed to months or years after the injury, symptoms are generally less severe, and are due to size reduction in the chest cavity (dyspnoea, orthopnea, respiratory distress), and partial or complete obstruction of herniated abdominal contents (nausea, vomiting, abdominal and chest pain). The physical signs often present in a diaphragmatic hernia include; diminished expansion of the chest, impairment of resonance, adventitious sounds, cardiac displacement, circulatory collapse, cyanosis, dyspnoea and asymmetry of the hypochondrium.[10]

9. Diagnosis: radiography

Plain chest radiographs are the one of the most accessible imaging modalities and a highly useful screening tool in cases of suspected diaphragmatic injury. Occasionally, the chest X-ray can show pathognomonic signs of a diaphragmatic injury. This may be either a nasogastric tube within the chest (Fig. 3), hepatic displacement into the right hemithorax, or herniated bowel loops within the chest, with or without focal constriction of the viscus at the herniation site known as a "collar sign".[6] Other signs suggestive of, but not diagnostic of diaphragmatic injury, include; irregularity of the diaphragmatic outline, elevated diaphragm, mediastinal shift without pulmonary or intrapleural cause and compression atelectasis of the lower lobe.[23] The overall diagnostic accuracy of chest X-rays is difficult to accurately assess but has been reported as ranging from 27 to 62% for left sided injuries and 17% for right sided injuries, although one report quotes diagnostic rates of as low as 3%.[2] The position of the liver under the right hemi-diaphragm reduces the likelihood of bowel herniation and therefore chest X-ray changes are less likely to be seen in right sided injuries.

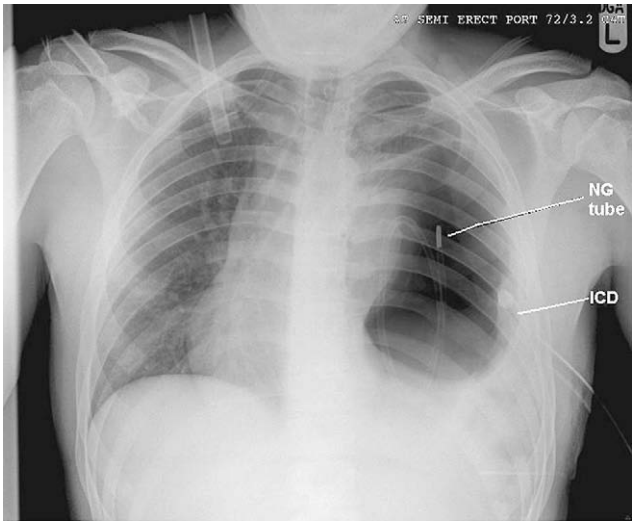

Fig. 3. Chest radiograph after insertion of the nasogastric tube (NG tube) confirming that the stomach is within the left pleural space. (ICD: intercostal chest drain).

Normal or non-specific radiographs are seen in 20–50% of all patients with diaphragmatic injuries.[4] Should initial X-rays be normal, repeated X-rays can be of use. This is helpful if the patient has been on positive end pressure ventilation, as herniation can be delayed until intrathoracic pressure falls to below that of abdominal pressure, allowing abdominal contents to herniate.[24] A recent case report advocates the use serial chest X-rays in suspicious cases of blunt trauma where a patient's mechanism of trauma could be deemed severe such as in a fall from height.[25]

Computerised Tomography (CT) scanning is perhaps the most useful diagnostic tool in the poly trauma patient. Not only can it provide information about diaphragmatic injuries, but also reveal other associated injuries. However, the patient does need to be haemodynamically stable. The introduction of helical CT in the 1990s has improved the early diagnosis of diaphragmatic injuries in the polytrauma patient. Conventional CT has a variable sensitivity of between 14 and 61% and a specificity of between 76 and 99%. Helical CT has a sensitivity of 71% (78% for left sided injuries, 50% for right sided injuries) and a specificity of 100%.[26] This improvement in diagnostic ability is largely due to elimination of artefacts from respiratory motion and the possibility of volumatic acquisition.[16] The findings on CT demonstrating diaphragmatic rupture include:

- Diaphragm discontinuity or segmental non-recognition (sensitivity 73%, specificity 90%)
- Intrathoracic herniation of abdominal contents (sensitivity 55%, specificity 100%)
- Constriction of herniated abdominal viscera (sensitivity 50–67%, specificity 100%)
- Visualisation of the herniated viscera against the posterior chest wall, the "dependant viscera sign" (sensitivity 100%, specificity 90%).[16]

Multidetector CT allows thinner slicing and more detailed imaging in a shorter time, and a more flexible image reconstruction. The accuracy of this new tool in diagnosing diaphragmatic injuries is yet to be established.[27]

Other techniques used include Focused Abdominal Sonography for Trauma (FAST) and Diagnostic Peritoneal Lavage (DPL). These can be good diagnostic tools however neither have proved useful for diagnosing diaphragmatic injuries.

Certain barium imaging studies can be used in the non-acute setting, which may visualise bowel in the chest. Magnetic resonance imaging (MRI) has been used with some success; however the precise role of MRI has yet to be clearly defined in diaphragmatic injuries.

10. Diagnosis: surgical

Considering the difficulty in confirming diaphragmatic injury radiologically, it is unsurprising that the diagnosis is often unsuspected, and only found at laparotomy. This can account for the diagnosis of up to 50% of blunt ruptures.[28] One article reports an 8% incidence of diaphragmatic injuries in patients undergoing laparotomy for blunt hepatic and splenic trauma, with a significant percentage of them being clinically and radiologically occult.[29] Depending on the location of a penetrating injury, certain centres explore all such patients with a laparotomy. One group describes performing an exploratory laparotomy on all patients with stab wounds to the chest below the nipples, or with penetrating injuries of the abdomen, back or flank.[30] Despite their higher level of negative laparotomies, very few cases of diaphragmatic injury were missed in the acute setting (one in 92), which they attributed to their aggressive surgical approach.

With the increasing utilisation of laparoscopy and thoracoscopy more diaphragmatic injuries are being correctly diagnosed, and in some cases repaired without the need for a laparotomy. Diagnostic laparoscopy remains an excellent tool for the detection of haemoperitoneum, solid organ damage and diaphragmatic lacerations.[3] They are especially useful for those patients who have no other need for laparotomy. Some groups advocate a period of clinical observation for those who are clinically stable, followed by diagnostic laparoscopy for all patients sustaining left thoraco-abdominal penetrating trauma.[3] In a prospective study of 34 haemodynamically stable and asymptomatic patients admitted with penetrating thoraco-abdominal injury, all patients underwent a diagnostic laparoscopy followed by either a confirmatory laparotomy or video-assisted thoracoscopy. Sensitivity, specificity and negative predictive value of laparoscopy for diaphragmatic injuries were 100%, 87.5% and 96.8% respectively. They concluded that laparoscopy alone is sufficient in excluding diaphragmatic injuries in asymptomatic and haemodynamically stable patients with penetrating thoraco-abdominal injury.[31]

Thoracoscopy has been used for diagnosis of diaphragmatic injuries for over a decade, and remains a very sensitive and specific tool with diagnostic accuracy in diaphragmatic injuries of between 98% and 100%.[10] However there are disadvantages to thoracoscopy, such as the time it takes to place the patient in the thoracotomy position, it does not allow repair of the diaphragm, and that it always requires a chest drain to be inserted, even if the findings are negative. The choice of whether to use thoracoscopy or laparoscopy remains controversial, relying often on the surgeon's preference and skill.

11. Treatment

Most morbidity and mortality is due to associated injuries. In the acute phase, treatment is primarily according to ATLS (Advanced Trauma Life Support) guidelines, and involves control of haemorrhage and gastrointestinal spillage. Attention should be directed at life threatening injuries first. Once the patient is stabilised, a thorough search for further obvious and occult injuries should be undertaken by way of a secondary survey. A nasogastric tube should be inserted with care, and should not be forced in case a herniated stomach in the left thoracic cavity distorts the oesophageal junction, resulting in a laceration in the oesophagus, stomach or both.[4]

At laparotomy, regardless as to whether the diagnosis is suspected or confirmed pre-operatively, a full examination of both diaphragms should be undertaken. After exploration of the abdominal cavity and retroperitoneum, the right diaphragm is visualised with gentle downward traction on the liver after dividing the falciform ligament. The left diaphragm can be visualised by applying gentle downward traction on the spleen and greater curvature of the stomach. The central tendon of the diaphragm should be carefully examined along with the oesophageal hiatus. Should no injury be found, care should be taken to relocate viscera into their original anatomical location.

Once an injury is identified, one group recommends delineation of the defect using sharp dissection, and placement of Allis clamps at the most medial and lateral aspect, as well as the midpoints of the superior and inferior boarders.[3] These clamps allow inspection of the ipsilateral thoracic cavity. This manoeuvre helps to investigate further thoracic injuries, and delineate the extent of cross-contamination of abdominal contents. A chest drain can be inserted and irrigation can be undertaken at this point.

All herniated viscera must be carefully reduced and relocated to its original position in the abdominal cavity. Devitalised diaphragmatic tissue needs to be carefully debrided, sparing as much muscle as possible. Failure to debride invariably leads to muscle

necrosis and compromises the repair. Diaphragmatic lacerations may be repaired by a variety of suture material and technique. Interrupted or horizontal mattress sutures are commonly used, but some surgeons prefer a running suture repair. The use of either absorbable or non-absorbable suture material is accepted in current practice. However the use of absorbable suture material has been recently questioned by one group looking at follow up of patients after diaphragmatic injury repair. They reported 13 patients followed up after a mean 48.5 months.[21] They found one recurrence of a diaphragmatic defect at 14 months, which was done with absorbable sutures. Another patient had a recurrence on day one post operatively, again following usage of absorbable sutures. All other repairs done were done with non-absorbable sutures, and were successful. Although the follow up was small in size, the authors suggest these findings provide a strong argument against the use of absorbable suture material.

Once repaired, the integrity of the suture line needs to be tested, using large tidal volumes to increase intrathoracic pressure, whilst directly viewing the repair line, and the motion of the hemi-diaphragm involved. Repeating the manoeuvre with the suture line submersed in sterile saline allows the operating surgeon to detect air leaks.

A thoracotomy is occasionally used as the only access for diaphragmatic repairs, whilst other times used as an adjunct to laparotomy, either via separate incisions or in continuity. One group revealed that of all diaphragmatic injuries discovered, 74% were repaired via laparotomy, 18% via thoracotomy, and 8% by a combined thoraco-abdominal approach. Diaphragmatic injuries can be repaired by a thoracotomy alone, however relocation of abdominal viscera can be quite challenging.[3] Certain authors recommend all repairs done via thoracotomy are followed by a laparotomy to further assess any intra-abdominal injuries.[3] They also recommend that should gross contamination be discovered at laparotomy, a thoracotomy should be performed to allow for copious lavage, followed by insertion of two large chest drains.

Uncomplicated diaphragmatic injuries, can be repaired laparoscopically. This can be done either with staples, or with laparoscopic suturing. This requires surgical experience but in the right hands can be highly effective.

Massive diaphragmatic destruction, caused for example by shotgun injuries, requires special attention. Invariably, there is gross disruption to the chest wall, and usually extensive associated injuries. Surgical options include relocating the hemi-diaphragm to a higher level by detaching it anteriorly, laterally and posteriorly, and re-attaching it superior to the thoracic defect, effectively converting a thoracic wound into an abdominal one. Occasionally local muscle flaps are required to cover the wound. Alternative solutions involve using prosthetic mesh to cover the diaphragmatic injury, although the risks of infection are high.[32]

12. Chronic phase

It is widely accepted that operative repair of a diaphragmatic injury is uncomplicated if done immediately, and difficult if delayed. Diaphragmatic defects invariably enlarge over time, due to the constant motion of the diaphragm and negative intrathoracic pressures. Often, progressive herniation of a viscus occurs, causing symptoms of obstruction or cardio-respiratory compromise. Further problems with adhesions, retractions, and diaphragmatic atrophy occur, with repair requiring non-absorbable prosthetic meshes or even muscle flaps. Suture line dehiscence is more likely if repair is performed in the chronic phase.[3]

Surgical repair is best undertaken via a thoracotomy, as it allows safe liberalisation of herniated viscus from the abdominal cavity. However a significant number of authors recommend the abdominal approach, even in the case of chronic injuries. As such, all patients should be considered individually, and the most appropriate incision decided upon by the lead surgeon.

Practice points

- The incidence of Diaphragmatic Injury is increasing due to the increase in Road Traffic Collisions.
- Diagnosis has been improved by the use of CT scanning in the acute emergency setting.
- Treatment can be either via a laparotomy or thoracotomy, or combined procedure. Laparoscopic repair is also an option.
- A broad and holistic approach should be adopted when considering a poly trauma patient and the possibility of diaphragmatic injury should be considered early to avoid late presentation and possible mortality.

Conflict of interest statement

The authors have no conflict of interest.

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Educational questions

Answer the following questions: true/false

1. Diaphragmatic hernias can occur during
   a. Blunt trauma
   b. Penetrating trauma
   c. In combination with more severe injuries
   d. Following pneumococcal infection
   e. After a pneumothorax

2. Embryologically the diaphragm is derived from the
   a. Septum transversum
   b. Body wall and pleuroperitoneal membranes
   c. Dorsal mesentery of the oesophagus
   d. Pharyngeal pouches 3 and 4
   e. Pharyngeal arches 4 and 6

3. Structures passing through the diaphragm
   a. The oesophagus passes through at T8
   b. The thoracic duct passes through with the vena cava
   c. The vagus nerve travels with the abdominal aorta
   d. The azygous vein travels with the thoracic duct and abdominal aorta
   e. The diaphragm makes up the inferior sphincter of the oesophagus

4. Regarding the function of the diaphragm
   a. It is an accessory muscle of inspiration
   b. It helps during defecation to empty the contents of the rectum
   c. Its main motor innervation is from the phrenic nerve
   d. It is responsible for 70% of the work during inspiration
   e. A transection of the brachial plexus can result in a hemi-paresis of the diaphragm

5. Physical findings that might indicate a diaphragmatic hernia include
   a. Decreased breath sounds
   b. Fractured ribs
   c. Flailed chest
   d. Audible bowel sounds in the chest
   e. Pectus excavatum

6. Pathognomonic signs aiding radiological diagnosis of Diaphragmatic hernia include
   a. A nasogastric tube in the chest
   b. Free air under the diaphragm
   c. Herniation of viscus in the hemi-thorax
   d. Stangulation of loops of bowel at the herniation site or "collar sign"
   e. Pneumothroax

Please select one correct answer from the list below:

a,b
a,c,d
a,c,e

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